

LABORATORY EXPERIMENTS FROM THE TOY STORE

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KEY WORDS: Elasticity, plasticity, strain rate dependence, extrusion.

PREREQUISITE KNOWLEDGE: This material could be taught to a typical student of materials science or manufacturing at the high school level or above.

OBJECTIVES: To qualitatively demonstrate the concepts of elasticity, plasticity, and the strain rate and temperature dependence of the mechanical properties of engineering materials.

To qualitatively demonstrate the basics of extrusion including material flow, strain rate dependence of defects, lubrication effects, and the making of hollow shapes by extrusion. The two parts may be two separate experiments done at different times when the respective subjects are covered.

To demonstrate the importance of qualitative observations and the amount of information which can be gathered without quantitative measurements.

EQUIPMENT AND SUPPLIES: 1) One or more containers (eggs) of formable putty (Silly Putty™, Nutty Putty™, etc.); 2) one or more clay extrusion presses (made by Play-Doh™, Fun Dough™, etc.); 3) ice and a bowl; and 4) a low power heat source (depending on the ambient temperature, this may not be required).

PROCEDURE: Part 1 of this experiment involves allowing the students to manipulate the formable putty to illustrate the definitions and concepts of the mechanical properties of materials. Figure 1 contains a picture of the putty and normal packaging container.

While the students are unwrapping the putty, the definitions of elasticity (recoverable deformation) and plasticity (non-recoverable deformation) can be reviewed.

1) The students may form the putty into a smooth ball and bounce the ball on a rigid surface from a height of about 10 cm and note the general height of the rebound and the lack of permanent deformation. The amount of deformation can be quantified by using a measuring stick.

The ball may then be placed in the bowl of ice and cooled. It will be noticed that the ball flattens on the bottom illustrating creep.

After the putty is cold, it can be reformed into a ball and bounced again from the same 10 cm height and the amount of rebound noted. The rebound height will be higher than when warm indicating an increase in hardness with decreasing temperature.

2. The putty can then be formed into a cylinder. The students pull the putty slowly lengthwise and note the extensive plastic deformation (Figure 2). This is a graphic demonstration of the concept of ductility. A note should be made of the relative amount of force needed to pull the cylinder.

Reforming the cylinder and quickly pulling it may result in some plastic deformation and a sharp break if the room temperature is below about 24 C (Figure 3). If it is summer without good air conditioning, the faster pulling will still give extensive plastic deformation.

Forming a cylinder and cooling it in the ice will give a better visualization. Slow pulling will give extensive plastic deformation (ductile) and fast pulling will result in a sharp break (brittle). The amount of force necessary to pull the cylinder should be greater than that needed for the warmer conditions.

The audience at the initial presentation of this paper suggested two other experiments along these lines. The first involved cooling the putty in liquid nitrogen and hitting it with a hammer when it was cold. The ball will shatter further illustrating the temperature dependence of deformation. The second suggestion was to also use torsion for the ductile-brittle versus rate of deformation experiment. This illustrates that the method of deformation does not change the material's reactions in these matters.

3. A relatively short cylinder can be formed (height about twice the diameter). Placing the cylinder upright on a flat surface and gently deforming it in the length direction with the flat of the hand will illustrate the concept of barreling common in upset forging. The material next to the hand and next to the table will expand less than the center material due to the friction between the putty and hand and the putty and the table.

4. The students should be given time to try other experiments with the putty. It has been observed that most students will play with the putty for quite awhile on their own.

Part 2 of this experiment involves the use of a clay extrusion press such as the Play-DohTM Fun Factory or the Fun DoughTM Super Play Shop. As seen in Figure 4, the press comes with a variety of die shapes all of which have

approximately the same cross-sectional area and thus the same extrusion ratio. The presses come with two containers of different color clay.

1. The students may take one color of clay and extrude it through different die shapes noting the relative amount of force needed. In general, more force is required for those dies with the larger amounts of surface area (many small holes versus a few large holes). This indicates the effect of friction.

2. The students should extrude clay using the tube die (bridge or spider die) and make hollow tubes (Figure 5). This is a concept which is difficult for students to understand in lecture. The addition of a little water to the die prevents rewelding of the two halves demonstrating the effect of surface contamination. (It has been noticed that the Play-DohTM spider die works better than the other brands).

3. Using one of the dies, the students should slowly extrude a shape. A second shape should be extruded using much greater speed. The first shape should have a smooth surface and the second should be irregular due to "speed cracking", a common extrusion problem. This can also be done on the same extrusion as illustrated in Figure 6. A careful application of a small amount of water to the inside die face and the front (die side) of the clay can be used to increase the extrusion speed without the speed cracking showing the effects of lubrication. (Note: This may be a little tricky since the water will dissolve the clay if too much is used. Oil may be used but may also react adversely and may be more difficult to separate afterwards).

4. Two experiments may be performed to demonstrate the material movement. In the first, two colors of clay are placed side-by-side with the intersection parallel to the extrusion axis. Extruding through a single hole die shows that the two colors maintain their respective positions. Placing the two colors so that the intersection is perpendicular to the extrusion axis and extruding demonstrates that the back color moves faster and moves inside the front color. The extruded shape can then be cut to show the extent of the movement. The amount of each color in a cross-section varies along the length of the extrusion as shown in Figure 7. Similar movement can also be demonstrated using the multi-small hole "spaghetti" die.

5. The students should then be allowed to experiment with the equipment.

SAMPLE DATA SHEETS:

- Putty: 1. Rebound height warm _____
Rebound height cold _____
Observations: _____
2. Relative amount of force cold _____
Relative amount of force warm _____
Observations (include description of fracture surface) _____
3. Sketch cylinder before and after deforming
4. Descriptions and observations
- Extrusion:
1. Die Shape Relative amount of force
2. Observations
3. Observations and sketches
4. Sketch before and after for both cases
5. Descriptions and observations

INSTRUCTOR NOTES: The relative measurements should be made into a numerical form such as 1 (low), 2 (moderate), and 3 (high). The students will generally tend to play with the equipment for a fair amount of time after the designated experiments are over. Some of their documented observations may be included in future experiments.

SOURCES OF SUPPLIES: The putty and the extrusion press can be obtained in most large toy stores (before Christmas is a good time to find them though both of these are usually available all year). It generally requires two putty eggs per student to give enough material to work with. These cost about \$3-\$4 per egg. The extrusion presses are less than \$10. These are all 1990-1991 prices in the Phoenix, AZ area. All of these should last a number of years except that new clay may be required every year. The clay costs about \$4 per 4 pack. (The clay becomes mixed and thus a generic off color. The mixing experiments require separate colors).

The measuring stick, if used, may be any available ruler or may be made by the students out a piece of paper with regularly spaced lines drawn on it.

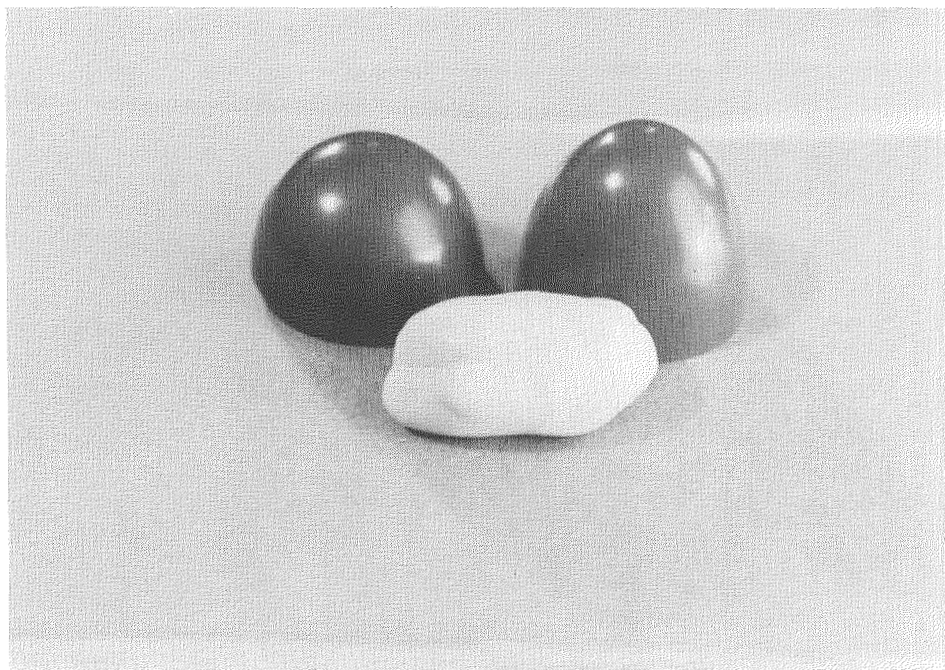


Figure 1: Formable putty and packaging.
The amount shown is from two eggs.

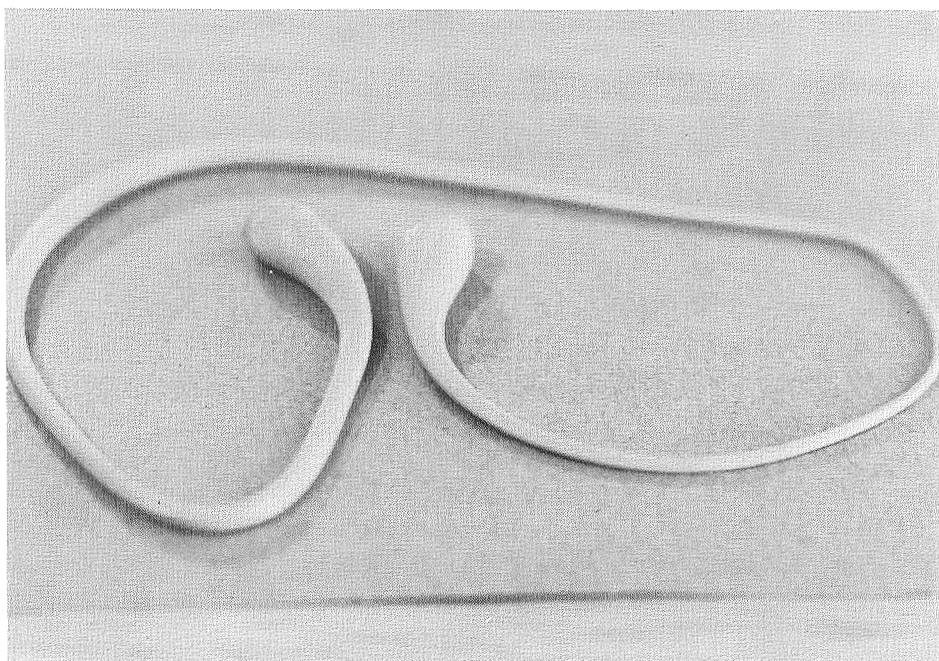


Figure 2: Deformed putty which underwent a
large amount of ductile plastic deformation.

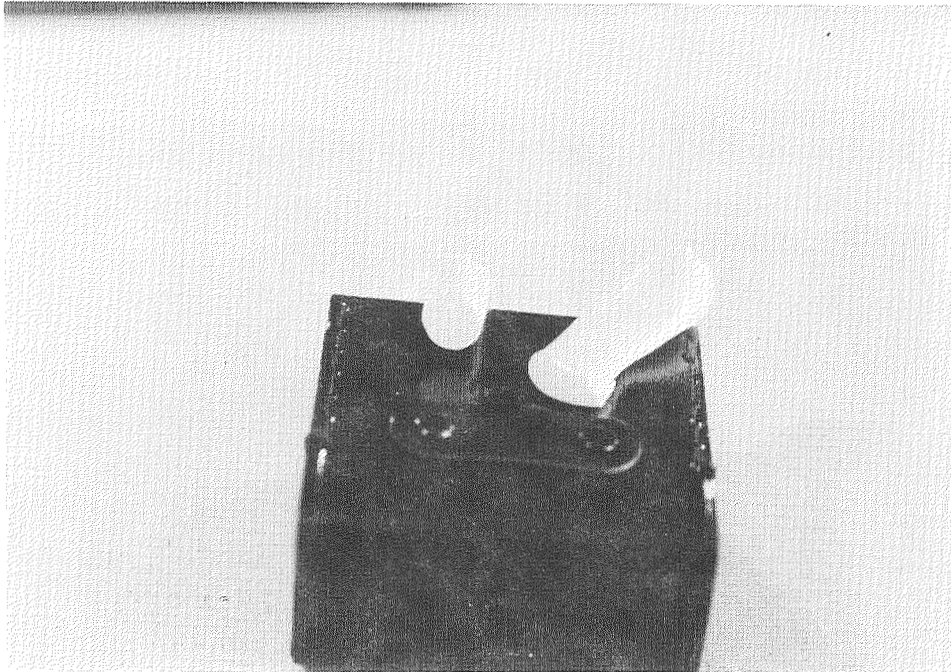


Figure 3: The fracture surface of the putty after brittle, high-rate deformation.



Figure 4: Extrusion press showing die selection and packaging.

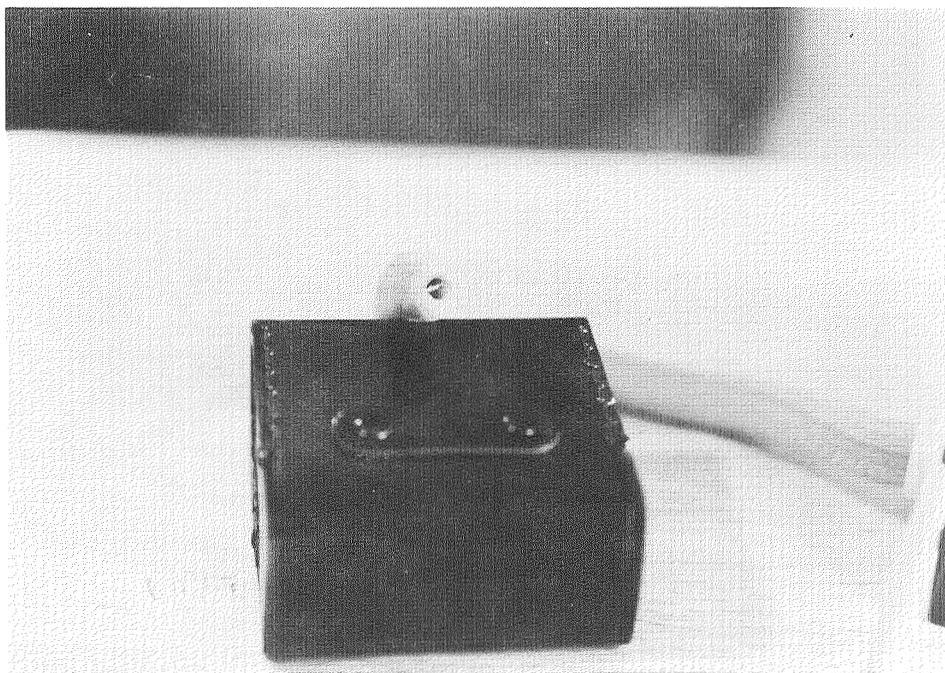


Figure 5: Hollow tube extruded from the Fun Factory.

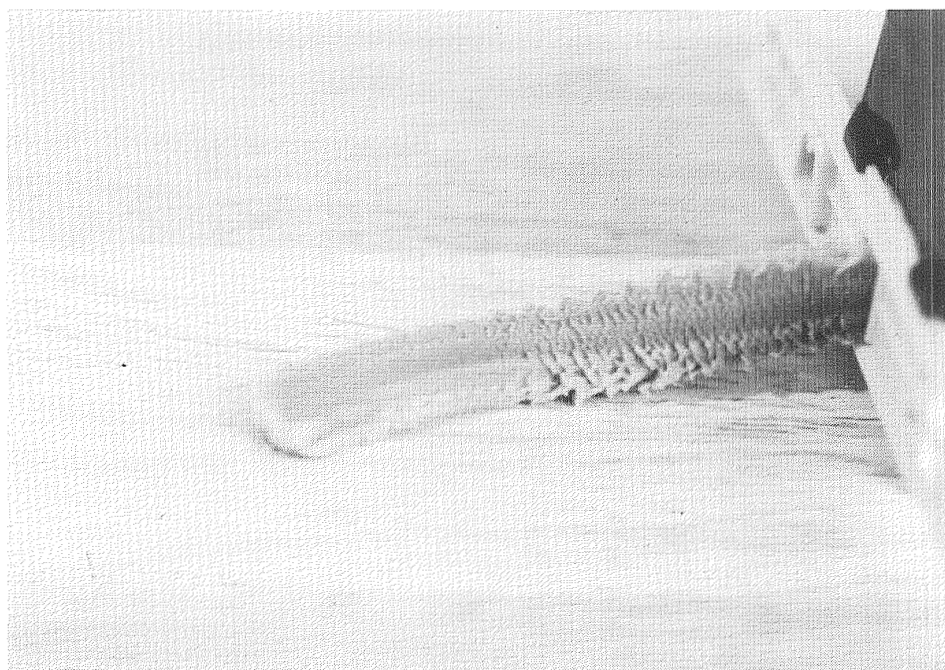


Figure 6: Rectangular shape extruded at slow then fast rates showing the transition to speed cracking.

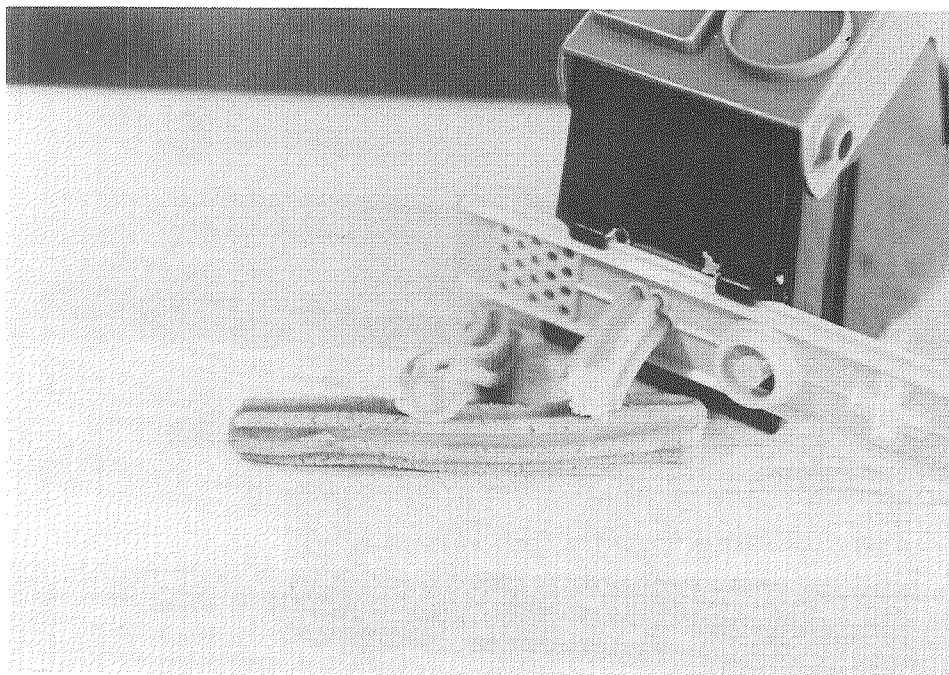


Figure 7: Shape extruded from two color dough arranged front-to-back in the press demonstrating the movement of the rear (lighter) color into the center of the front (darker) color.